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Original Article

The study of the quality and capacity of equipments' functionality and non-structural vulnerability in selected Tehran general hospitals during an earthquake

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Abstract

Introduction: In this research project, we studied the quality and capacity of the equipments' functionality and non-structural vulnerability of seven hospitals in the city of Tehran during an earthquake. **Materials and Methods:** The research's place was general hospitals with private and governmental management; the research society was all Tehran general hospitals where a random sample of seven general hospitals were studied in eleven different categories. The methodology of the study was descriptive cross sectional; sampling was random simple and the instrument for the study was World Health Organization (WHO)/Pan American Health Organization (PAHO) Standard checklist. The lowest levels of functionality were observed in emergency exit systems, communication systems, furniture, and equipments. **Results:** The heating and cooling systems, air conditioning of specific sections, medical gas systems, fire detection and extinguisher of most hospitals in the study were functioning at satisfactory levels. Even though in general assessment, 56% of the hospitals were functioning at satisfactory levels in non-structural features, in every hospital the critical, vital, and effective sections were functioning at an average and some in even low levels. **Conclusions:** In conclusion, non-structural assessment of hospitals under the study did not show the satisfactory level of ability to respond appropriately at the time of crisis. There are existing standard guidelines for the safety of non-structural elements in hospitals that explain all the necessary steps needed to maintain and protect these components in great details. Therefore, any strategies for improvement in aforementioned components are due to the establishment of better laws and regulations. Our suggestions procedures are as fallowing: 1. Official quality assessment of all hospitals, detection of non-structural safety problems, and introduction of strategies to solve these problems. 2. Passing of an official, mandatory safety and response capability bill for hospitals and medical centers. 3. Establishment and enforcement of incentive and fines for the medical center management to ensure the ability to respond to crisis and/or national disasters.

Key words: Non-structural vulnerability, risk, safety level assessment

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Introduction

At the time of the earthquake, providing emergency treatment to the casualties is one of the most important responsibilities of the medical centers. These centers should be fully equipped and have a detailed plan to function properly in the emergency situation. This detailed plan is called "Quake Crisis Management."[1] Quake Crisis Management means establishing management (structural) and engineering (physical) planning and arrangement to reduce the destructive effects of earthquake.[2] Hospitals incorporate several components and in order to provide the best services to the patients, all those component need to work together and interact properly, and deficiency of any section may effects the whole process. One of these components that need a close attention is the non-structural component. In general the non-structural component includes architectural details, communication, electrical systems, mechanical components, and medical equipments. Load baring and non-load baring walls, dropped ceiling, panels and dividers, windows, air conditioning, heating, ventilation and cooling systems, steam engines, elevator, emergency generator, liquid storage tanks, Communication and medical equipments are also considered non-structural components of the hospitals. Previous studies showed only 15% of construction budget goes to non-structural components, and 85% of that goes to architectural, mechanical, electrical components, and storage; we can also add the expense for medical equipments.[3]

During the 1995 Kobe Japan's earthquake, in many hospitals, massive damages were caused by the falling of the unsecure shelves, movement of equipments on wheels and other equipments, unsecure laboratory equipment, and destruction of medical offices. Heavy medical machines, like magnetic resonance imaging (MRI), X-ray, and tomography machine showed a movement between 30-100 cm. There were also substantial damages to angiography machine and other equipments.[4]

City of Tehran with its considerable size and population is not immune to earthquakes. Considering this city's geological and topographic situation a powerful earthquake is long overdue. Existence of 15 faults (cracks or fracture in earth's crust) in this area is one of the main reasons that put this city in danger of earthquake. There are three main faults in Ray, Masheh, and Niavaran district in Tehran, which potentially can cause an earthquake with the magnitude of 7 on the Richter scale.[5] Unplanned expansion of the city, metropolitan structure, and fundamental features that are not properly designed to tolerate the earthquake, make Tehran more vulnerable than other cities. Geologists, based on their risk analysis and probability techniques, predict great possibility of high magnitude earthquakes for Tehran in near future. Kambod Amini Hossaini and Mohammad Kazeme Jafari in their studies about Tehran's vulnerability to the earthquake stated that because of Tehran's geological condition and geographical location, presence of several active faults, tectonic evidence, and the history of high magnitude earthquakes, this city has greater risk of another high magnitude earthquake. In spite of high risk of earthquake and scientists' warning, proper strategies, to reduce the death tolls and damages are not in place yet. Mehdi Heydari in financial vulnerability and vital transportation routes, aftermath of earthquake, stated, large population, vulnerability of its vital transportation routes, concentration of embassies, congress, important social and financial establishment, and other complexity of the big cities put Tehran in a unique situation. High magnitude earthquake not only cause severe damages to this city, it would also effects many other cities and even may cause international problems. Rasol Afzali in the study of Tehran's vulnerability and managing political damages of possible earthquake stated a high magnitude earthquake in the big city of Tehran may lead to wide spread political crisis by endangering the functions of the city's constitution. Massive relocation of the large number of people after the earthquake and providing temporary shelter and medical care for casualties are some of the problems that may lead to the political fall down. Preparation, and long term and short term planning in many different levels of management are necessary to take care of these problems. Considering all these factors, plus increasing population, shows how important it is to plan for managing these crisis, particularly in medical centers, one of the most important establishments at the time of any national disaster.[6] This critical situation encourages the researcher to study this subject. The goal of this study is a general assessment of the quality and capacity of equipments' functionality and non-structural vulnerability in seven Tehran's general hospitals, and local assessment of the hospitals in one of the city districts (district 4) during an earthquake.

Materials and Methods

The research's Place was general hospitals with private and governmental Management; the Research Society was all Tehran general hospitals where a random sample of seven general hospitals were studied in eleven different categories. Four hospitals were chosen from Tehran's district 4 and three hospitals were chosen from other districts. The tools we used for this study were collecting data from reliable sources and using the standard checklist for assessment of the equipments' functionality and non-structural vulnerability during emergencies and crisis. In this study, we used WHO/PAHO standard checklist. This checklist is used to measure the vulnerability hospitals. In similar study this checklist was used for the assessment of crisis management during earthquake for Shafaa Hospital in Kerman.[7] This checklist measures vulnerability of hospitals during emergencies based on the equipments' functionality and non-structural vulnerability. We used the checklist for seven hospitals in eleven different categories. These categories includes electrical systems, communication systems, emergency fuel tanks (gasoline and natural gas), water supplies, medical gases (oxygen, nitrogen, etc.), waste management systems, the heating and cooling systems, air conditioning (HVAC) of special departments, fire detection and extinguisher, emergency exit systems, furniture and equipments, and architectural details.

The data was entered in Excel software and quantitative data was calculated. In this assessment, we assign 1 for low, 2 for average, and 3 for high safety level. We studied 6 items in electrical system, 4 items for communication, 4 items for emergency fuel tanks (gasoline and natural gas), 6 items for medical gases (oxygen, nitrogen, etc.), 2 items for waste management systems, 6 items for the heating and cooling systems, 4 items for fire detection and extinguisher, 6 items for emergency exit systems, 5 items for furniture and equipments, and 12 items for architectural details.

Results

For anonymity reasons in this study we do not reveal the names of the hospital and instead we use the name of the district were those hospitals located. We studied seven hospitals in eleven different categories. These categories includes electrical, communication, emergency fuel tanks (gasoline and natural gas), water supplies, medical gases (oxygen, nitrogen, etc.), waste management systems, HVAC of special departments, fire detection and extinguisher emergency exit systems, furniture and equipments, and architectural details. Table 1 shows the results of this study.

According to the results, 56% of hospitals under the study had satisfactory safety levels of electrical systems, only 29% had satisfactory communication systems, 43% had satisfactory safety emergency fuel supplies, 57% had satisfactory water supplies, 86% safety levels for medical gases, 71% had satisfactory waste management systems, 71% had satisfactory condition in HVAC of special departments, 57% had satisfactory condition for fire detection and extinguishers, only 14% had satisfactory emergency exit systems, 29% had satisfactory conditions for furniture and equipments. The condition of architectural details of hospitals in emergency situation is more important than any other factor, therefore the architectural details always need to function perfectly. Eighty-six percent of the hospitals had satisfactory architectural detail condition. General assessment of the non-structural functionality of two hospitals in district 4 showed less than 30% and in district 9 they showed less than 40% readiness. Other hospitals in district 4 showed 60% to 80% readiness to face a crisis during the earthquake.

Discussion

General assessment of the non-structural functionality showed 50% of the hospitals had good condition: 56% of them showed over 60% readiness and 14% of them showed under 30% readiness. A study by Sayed Hesam Sayedin[8] and associate (1387) about vulnerability of organizations and management of one selected hospital during crisis, showed average non-structural vulnerability. Another study by Arab[9] and associate was done about the proper performance during the earthquake on the hospitals working under university of medical science and medical treatment services. Regarding the safety of equipments, the study showed 46% of the hospitals had satisfactory condition and 14% of hospitals showed low levels of preparedness in earthquake condition. Result of this study is similar to the results of the other studies about hospitals' readiness during crisis, and confirming that the non- structural functionality of the hospitals during earthquake is around high-average. But we have

Table 1: Non structural safety level collation of study's hospitals for earthquake's risks

Hospitals	Electrical Systems	Communication Systems	Emergency Fuel System	Water Supply System	Medical Gases	Waste Management System	Hvac System	Fire Detector and Extinguishing System	Emergency Evacuation System	Equipments and Furnitures	Architectural Elements	Hospital's Non-Structural Function Readiness
No.1	18	11	10	17	17	5	16	8	8	14	28	73%
No.2	10	5	4	6	10	6	12	9	10	10	36	27%
No.3	11	8	8	12	13	5	12	8	7	9	25	27%
No.4	14	12	11	15	14	6	14	11	9	9	28	82%
No.5	17	9	6	12	15	4	15	9	15	10	34	64%
No.6	13	4	7	13	13	2	14	7	7	8	16	36%
No.7	12	7	10	14	15	6	13	9	11	11	28	73%
System's Readiness of Study's Hospitals	56%	29%	43%	57%	86%	71%	71%	57%	14%	29%	86%	-
Low Level Safety's Peak for each Systems	6	4	4	6	6	2	6	4	6	5	12	61
Medium Level Safety's Peak for each Systems	12	8	8	12	12	4	12	8	12	10	24	122
High Level Safety's Peak for each Systems	18	12	12	18	18	6	18	12	18	15	36	183

to consider that different elements of the non-structural functionality of the hospitals work like links of a chain. Weakness in any of those links may lead to the destruction of the whole system "Weak Link Theory."[10] Therefore, the study of non-structural functionality as a whole is not a good representative for the hospitals' performance during crisis. That is why study of the functionality of each of non-structural element separately and coming up with strategies to improve their functionality is more realistic. In this section we try to study each non-structural element and provide practical strategies to improve their functionality.

The 1994 earthquake in Northridge[11] California led to evacuation of 14 hospitals. Black out was the main reason of evacuation. In this study the electrical systems of 44% of the hospitals did not perform properly. Our idea for improving the safety of the electrical systems is proper installation of the main cables to insure their resistance to tearing as a result of displacement during the earthquake. Hospitals should also consider using rechargeable (battery operated) generators for emergency lighting at the time of earthquake to avoid large number of casualties during emergency evacuation. They also should have a back up electric system for the vital part of the hospital. Only 29% of hospitals under the study had proper communication system. Sayedin[12] and Jamali studied the management of the communication and information system during crisis in Iran. Their study showed the most important and a vital element for any operation, especially crisis management, is the information system. Accepting patients and casualties require external communication as well as internal communication and coordination between different departments within hospitals. In this regard the safety and control of cables and equipment of communication systems and establishment of many layers of communication could ensure reducing the risks during crisis. Only 43% of the hospital had proper emergency fuel tanks. Currently, most of the hospitals in Tehran utilize natural gas, which makes it hard to supply this fuel during crisis. We suggest hospitals should be able to operable with two alternative fuel system. Amini in the study of the fuel supplies in Atiyeh hospital stated that the capacity of the fuel tanks is suitable for functioning in the case of emergency, but the tanks itself need adjustment. He also emphasized on using flexible attachments to connect the pipes to the tanks to increase the tolerance to shaking during earthquake. In that study, 53% of hospitals had satisfactory condition regarding the safety of water supplies. Although most hospitals equipped with emergency water supplies, their system, however, is design to function in normal conditions and could not operate during a crisis. Amini in assessment of water supplies in Atiyeh hospital stated the capacity of the hospital's water tank was about 69,000 liters and the hospital need to add one or two more tanks with the capacity of 60,000 liters. In general, 86% of the hospitals showed satisfactory safety condition regarding medical gases. GeoHazards International.[13] in study of Initial Seismic Vulnerability Assessment at Women's Hospital "Kathmandu," medical gas, both the supply systems and the distribution systems can be vulnerable to earthquake damage that can prevent the hospital from delivering essential medical services following an earthquake. Seventy-one percent of hospitals in our study showed satisfactory waste management condition. In systematic waste management of medical centers, established and reliable plans for collection and removal of the containers and waste materials from inside sources and transferring them outside is necessary. Therefore, waste management and transportation of hospital wastes includes two separate steps; collecting waste materials from inside sources, and transferring them outside of the hospital. Every hospital has designated area for temporary collection of the waste and some hospitals are equipped with trash burners. We should keep in mind, during crisis following an earthquake the number of patients and casualties significantly increases and as a result the volume of the medical waste increases along with it. Therefore the existing systems and equipments for separating, burning, and transporting waste could not function properly. We suggest designing a protocol that all hospitals should follow, and demand a designated area for temporary emergency collection and storage of the medical waste. This kind of storage tank should have specific size, so they could be transported by trucks. 71% of hospitals had satisfactory HVAC in special departments. These systems are made of many parts and pieces that even in ordinary condition may break or malfunction. Therefore one of the sections that we may anticipate its malfunction during an earthquake is the HVAC. All the equipments in these systems should properly be stabilized and flexible attachments should be used in connecting pipes and cables to increase their tolerance to shaking during an earthquake.[14] 57% of hospitals in our study had satisfactory fire detection and extinguisher systems. These systems, in every hospital under the study, were at average and fair condition. Most of the hospitals have fire detection and warning systems, and fire extinguisher. Although we should consider that after an earthquake city's fire department could not respond and perform as fast as during non-crisis conditions. This implies the fire department may be unable to respond to crises in hospitals in a timely manner. These conditions may lead to the spread of fire and destruction of many areas of a hospital. Some of the strategies for providing the water supplies for large buildings are the installation of strong pumps, with fuel operating generator, and building pools, for other uses in ordinary circumstances and for providing water during emergencies. A comparison of 1994 Northridge earthquake and 1995 Kobe earthquake showed using the pools were very useful.[15] During Northridge earthquake they could put out the fire in six hours by using water from the pool, whereas in Kobe they failed to stop the fire by using under-ground water supplies.[16] In our study, only 14% of hospital had satisfactory emergency exit systems. In most hospitals there was not any sign to show emergency paths and emergency stairs. Shojaee in the study of emergency exit systems in Medical Science University training hospitals in

Iran stated, although emergency paths and emergency stairs existed in every hospital, but the signs were not display properly, the staff did have the proper training and in many departments, including ER, some of the emergency doors were locked. Establishing proper rules and regulations for labeling hospital emergency paths and periodical mandatory training of staff for evacuation of patients and relocation of the equipment that obstruct the emergency paths is necessary. Only 29% of hospitals had satisfactory safety levels for furniture and medical equipments. The study of the maintenance of medical equipments in Arak hospital showed 53% of medical equipments did not function at proper levels, 43% were not installed in proper location and did not have necessary operations manuals and instructions, 49% were not up to the standards and 21% were not safe for operators and patients. In order to address these problems, all equipments and furniture in the hospitals should be secured by installation of safety bolts and screw, cabinets should be locked, shelves and computers should be secured by the installation of safety straps, brackets and braces. 86% of hospitals had safe architectural details. Although architectural details may not have a direct impact on hospitals' functionality, damage and destruction of these components during an earthquake may disrupt the functionality of different departments of hospitals. If dropped-ceiling, interior designs, stucco and plaster, non-load baring walls and dividers are not connected to the main frame of the building properly, they could be highly vulnerable. In the study of vulnerability of medical centers during crisis, Sadjadi stated during an earthquake, destruction of room dividers, exterior damage, collapses of dropped-ceiling, dislocation of window and glass doors, and broken glass are all part of anticipated non-structural damages of an earthquake.

Increasing the non-structural safety level

Reza Etehadi and Taregh Mehdi in the study of non-structural damages to hospitals and medical centers studied the possible damages to these structures during a medium magnitude earthquake. They stated an earthquake may not destroy the building, but hospitals may not be able to function as a result of non-structural damages. There are plenty of engineering applications, standards guidelines and enormous studies available to ensure non-disruptive function of hospitals during crisis. These resources explain the necessary steps for maintaining and protecting these components in details. These steps could vary from basic common-sense tasks to complicated and professional preparations. Some of these preparations are helping with non-structural functionality and some of them reducing the impact of disruption. In order to choose the proper methods of providing non-structural tolerance, especially for hospitals, we should seek help from consulting and engineering firms. It is also necessary to establish better laws and regulations to improve the non-structural safety of hospitals during crisis. Our suggestions, for step-by-step procedures, for improving the non-structural safety of hospitals during crisis are as fallow:

- Official quality assessment of all hospitals, detection of non-structural safety problems, and introduction of strategies to solve these problems
- Passing of an official, mandatory safety, and response capability bill for hospitals and medical centers
- Establishment and enforcement of incentive and fines for the medical center management to ensure ability to respond to crisis and/or national disasters.

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